SAFAL: Surface Analysis For Autonomous Landing of UAV

Abhishek Garg[1[0009-0008-4769-160X]] |
, Utsav Bansal[1[0009-0007-3531-1588]]
, Ankur Bhargava[1[0009-0002-3133-8365]]
, and Rahul Johari[⋆1[0000-0002-7675-8550]]

SWINGER : **S**ecurity, **W**ireless, **I**oT **N**etwork **G**roup of **E**ngineering and **R**esearch,
University School of Automation and Robotics(USAR),
Guru Gobind Singh Indraprastha University, Delhi, India

Abstract. In today's fast moving world, the use of UAVs (Unmanned Aerial vehicles) is widespread in scenarios of defence, relief and rescue missions, medical field and many more. However, the fundamental challenge is the incapacity of UAVs to detect safe landing surface and land on it autonomously. Lack of this would expose one to damage during manual landings or crash landings in emergency operations. The solution that this research **SAFAL: S**urface **A**nalysis **F**or **A**utonomous **L**anding sought to provide involved creating a system, that UAVs could use for self-detection of safe landing zones. The drone captures images using its onboard camera and then uses a custom developed algorithm to identify suitable landing surfaces. After the drone takes the image, the algorithm then scans for surface features to determine if the area is safe to land. If a safe landing place is identified, the UAV lands autonomously based upon pre programmed parameters for landing. The simulation proved that it is possible for the UAVs to detect and land at safe surfaces independently. This increases their capability to work in a variety of environments as well as makes it safer during important missions. The simulation of this process was conducted on MATLAB R2024B. Image processing was done using OpenCV library and the backend API were developed using the Python, FastAPI library. Frontend interface was developed with the help of NextJS.

Keywords: UAV; Surface detection; MATLAB Simulation; Autonomous Landing ; SAFAL

1 Introduction:

The Unmanned Aerial Vehicles (UAVs) have seen significant advancements over the past few decades. It was initially tested for use in defence sector but now it

⋆ corresponding author

finds it's application in many industries and sectors like relief and rescue operations, agriculture, environmental monitoring, logistics, recreation and the list continues to increase over the years. With vast range of benefits, UAVs has also encountered some significant challenges one of which is autonomous surface detection and landing. Traditionally UAVs landing system was majorly dependent on GPS data and predetermined landing spots. These systems were helpful and also sufficient in controlled environment but for challenging environments like uneven terrain, landslide hit areas or any other disaster hit areas, dense forest, low GPS compatibility and many more, it becomes difficult for these systems and might fail. This could also result in damage or crash of the UAV. So, a system was needed which could work on real time scenarios and is compatible with dynamic environment. So, this research focuses on these issues and have solved the need for real time decision-making in UAVs using vision and LiDAR sensors. This paper is focused on proposing an advanced system architecture using these technologies which are gaining popularity in similar applications and are being widely used. Each surface is assigned a rating based on its suitability for landing. A highly favorable surface receives a full score, a moderately suitable one receives an average score, and an unsuitable surface receives a score of zero. Additional factors like wind, battery percentage, position of the UAV also contribute to the final rating. If the overall rating exceeds a predefined threshold, the UAV proceeds to land; otherwise, it searches for an alternative landing spot. So, through this paper, these limitations have been addressed for traditional landing systems and proposes an advanced and intelligent system which also works on real time and has the ability to make decisions in dynamic environment.

2 Applications of Unmanned Aerial Vehicles (UAV)s :

The Unmanned Aerial Vehicle (UAV) initially started to help military in surveillance has now become a multi-purpose aerial system which serves various needs like commercial, civilian etc. Drones finds its applications in various domains which are explained below: -

- **Military and defence** - most modern drone technology has emerged from military needs and defence is its largest application area in today's market. Drones help in various ways for defence like it can autonomously land in debris-filled or uneven surface to deliver relief resources like medical supplies. It can also conduct search and rescue missions in areas which are difficult for humans to reach and also do timely surveillance in areas which are not accessible to humans.
- **Agriculture** - UAVs can land safely and smoothly in farms at remote areas after it has performed its tasks like inspecting, seeding, watering, spraying and many more.
- **Logistics** - with autonomous surface detection and landing of UAVs, logistics and delivery services will get the most benefits as last mile deliveries usually don't have a dedicated space for landing of drones and with this technology, it can precisely deliver goods at its final destination even if the

land terrain is uneven. It will also reduce the delivery time and increase its efficiency.

– **Monitoring and Inspection** - UAVs helps in regular and precise inspection and monitoring of national highways, wetlands, forests, wildlife centuries and improves the data collection, wildlife tracking and surveys using autonomous operations.

Fig. 1: Delivering medical support in flooded areas

3 Challenges and Issues of Unmanned Aerial Vehicles (UAV)s :

Although UAVs are used widely in defense, disaster management, logistics, and agriculture, there are still outstanding issues regarding autonomous surface detection and the safe landing of UAVs in complex terrains. To keep the sensors input accurate and credible is a major challenge. UAVs greatly rely on LiDAR, ultrasonic sensors, RGB and thermal cameras to make dynamic real-time assessments of the terrain. However, sensor's accuracy is quite often impaired by external factors like mist, strong storms, fall of snow, air pollution or poor visibility. Consequently, the information that arrives to the system may be incorrect or deficient, and this decreases the ability of the UAVs to land safely.

Trained models, even expert models, often fail in unanticipated or irregular environments. A disaster zone littered with rubble, for example, a wet, glossy, or mirror-like surface that is not found in training samples, exposes a real big barrier to ensure AI operates effectively in the unpredictability of the real world. The environmental factors in simulations or controlled testing are not the same as the uncertainties and untested conditions of real environments. Although it may be made safe, a landing zone may quickly become dangerous due to the sudden appearance of moving objects or change in conditions. In practical situations, the UAV would need to frequently revise and update its landing strategies, thus requiring rapid responses and computational agility.

Standardizing conditions of the testing of UAVs has considerable practical challenges. Because of different climatic and geographical settings, it is difficult to establish a standard interface to measure competence at which UAVs land. Optimizations of the system are frequently necessary for every new application, preventing widespread deployment.

The ability of drones to land themselves automatically raises questions as to who would be liable if things go wrong or an accident occurs. When a drone does not know how to interpret its surroundings properly, and therefore crushes onto any moving car or private property, then it is particularly difficult to determine who is responsible for this. Legal and ethical considerations also fail to facilitate the widespread deployment of urban scores of fully autonomous landing systems. Every obstacle including environmental, technological, legal and ethical considerations compounds complexity of implementation of this technology.

4 Problem Statement:

Unmanned Aerial Vehicles (UAVs) or drones have become bigger in significance in sectors such as defense, agriculture, disaster relief, environmental conservation and logistics. However, one of the greatest and common challenges in deploying UAVs is getting them to land safely and autonomously in complex and GPS-free terrain. Traditional UAV landing solutions are primarily GPS-based and rely on predefined or user-specified landing points. These systems can be highly satisfactory under laboratory conditions, but often experience severe problems or failures in dynamic and unpredictable environments like natural disasters (landslides or earthquakes), thick forests, and urban areas where GPS signals are not available. Such environments place significant demand on autonomous landing, as UAVs often struggle to adapt quickly enough to ensure safe landings which dramatically increases the risk of crashing, failure of missions or possible loss of equipment. In addition, insufficient surface detection capabilities prevent the UAV from accomplishing effective missions where operators are not present. The state of technology today is not sufficient to make dynamic decisions about the risks of terrain, surface stability, or environmental constraints in descent, which finally impacts overall reliability and performance. The pressing nature of this issue escalates based on the increasing use of UAVs to execute sensitive tasks related to disaster relief, military operations and automated delivery systems. Without an advanced and real-time sensor-based landing system, UAVs are incapable of operating fully autonomously in complex situations. There is, therefore, a critical necessity for the design and implementation of an advanced system which will include real-time surface sensing, autonomous decision-making, as well as the most current sensor technologies, including LiDAR, ultrasonic sensors, RGB and thermal camera, coupled with machine learning and computer vision algorithms. Such a system, if implemented, will greatly enhance UAVs' safety and flexibility in operations and will allow them to maximize their potential in complex real-world situations.

5 Literature Survey

Xin et al. in their research paper had explained the significance of autonomous landing of UAVs.They categorised the landing conditions into three main types, static landing condition (landing on labels like "H", "D", ArUco Code), dynamic landing conditions (landing on moving/unstable vehicles, platforms,ships) and complex landing conditon (disaster impacted area, uneven landing pads). Traditional landing technologies like image processing may face issues or drawbacks like environmental issues, processing time, delay in processing. Integration of sensors like LiDAR, Camera may enhance the operational capability of the vision based autonomous landing of UAV.

Bin Fang et al. in their research paper have explained that autonomous landing in GNSS (global navigation satellite system)-denied environments of fixed-wing UAVs poses large challenges because of their high speed, inability to hover, and their long operating ranges. Classical approaches doing this via GNSS or vision-based trickery are limited in scalability, accuracy and day/night operability. To close these gaps, the authors present a multi-sensor fusion-based landing system with the fusion of near-infrared and visible cameras, laser-based distance module, and a novel landing guidance window framework. This configuration guarantees high precision detection of UAVs over a wide spatial range (up to 1200 meters) and under different light conditions. The proposed system has mean errors less than 2 meters under dynamic day-night landings or with GNSS-denied situations. Comparative experiments on two UAVs demonstrate that it outperforms current vision-based or radar-based methods in terms of both accuracy and robustness which makes it appropriate to use in crucial fixed-wing UAV operations in complex environments.

Konstantinos A. Tsintotas et al. in their research paper states that autonomous UAV landing in emergencies or GPS failure is particularly important and the existing approaches tend to ignore the surface conditions and focus on the platforms to land on. This paper proposes a low complexity perception pipeline utilizing three downward facing laser range-finders for the purpose of evaluating terrain slope and surface obstacles prior to landing. The system, validated on a hybrid VTOL (vertical takeoff and landing) fixed-wing UAV (micropilot unit RX-4), measures ground slope through estimating the dominant plane using range finder data and uses a RANSAC(random sample consensus)-based outlier detection approach to investigate flying safety. The algorithm executes in real time efficiently (150 ms per full cycle) and was tested on flat, inclined and rocky surfaces. Unlike high-complexity vision or GPS based techniques, such as a low level platforms, this lightweight system guarantees safe, fast, low-computation autonomous landing decisions based on laser-only terrain analysis.

Rahul Johari et al. in their research paper aggregates and analyzes, a wide variety of literature related to UAVs, including routing problems, areas of application, and simulation tools. The paper classifies recent work (which depends on routing paradigms such as TSP-D (traveling salesman problem with drone), VRP-D (vehicle routing problem with drone), and multi-objective optimization) for application to transportation, monitoring, and data delivery. It summarizes different routing strategies, including: topology-based, location based social nodes and latency-aware protocols but it closely examines their problems with congestion, high latency and energy sustainability. The application specific studies of UAVs include military operations, forest fire monitoring, agriculture, search-and-rescue and space research revealing flexibility and developing coverage of UAVs. The paper concludes that although drones have given promising results throughout several domains, there is a need for improved security, better synchronization APK (adaptive positioning kinetics) strategies and strong autonomous control for future deployment.

Jiahuan Li et al. in their paper sets out the vision-based autonomous UAV landing system that has been developed specifically for a maritime environment where GPS is not reliable. It fuses the improved SSD (single shot multibox detector) deep learning model for precise detectability of small- targets with the KCF (kernelized correlation filter) tracking algorithm for high-speed action. The complementary filtering approach combines both to obtain a system that obtains 93.3 percent detection accuracy and functions at 91 Hz. This dual threading architecture provides both accuracy and real time responsiveness, making it very ideal for UAV ship landing operations.

6 Methodology:

6.1 Algorithm:

Entities and Abbreviations:

1. D — Drone or Unmanned Aerial Vehicle(UAV)
2. D_{tra} — D Trajectory
3. D_B —D Battery
4. D_{acc} —D Acceleration
5. E_v — Environment
6. D_p — D position
7. D_{Cv} — Camera Vision
8. D_v — D velocity
9. FM_{auto} — Flight mode autonomous
10. FM_m — Flight mode Manual
11. S_{sc} — Surface scan score
12. S_{scd} — Surface scan command
13. G_s — Grassy surface
14. S_s — Sandy surface
15. O_s — Oily surface
16. W_s — water surface
17. C_s — Concrete surface
18. A_s — Asphalt surface
19. F_M — Flight mode
20. D_{p1} — D_p for G_s

21. D_{p2}— D_p for O_s
22. D_{p3}— D_p for W_s
23. D_{p4}— D_p for C_s
24. D_{p5}— D_p for S_s
25. D_{p6}— D_p for A_s
26. E_{lc} — Execute Landing Command
27. F_M — Flight Mode
28. SAP_{st} — Surface assesment parameter stability == 0.4
29. SAP_f — Surface assesment parameter flatness == 0.3
30. SAP_g — Surface assesment parameter grip == 0.2
31. SAP_s — Surface assesment parameter safety == 0.1
32. D_{t1} — Distance from D_{p1} to D_p
33. D_{t2} — Distance from D_{p2} to D_p
34. D_{t3} — Distance from D_{p3} to D_p
35. D_{t4} — Distance from D_{p4} to D_p
36. D_{t5} — Distance from D_{p5} to D_p
37. D_{t6} — Distance from D_{p6} to D_p
38. D_n — Direction for navigation

Pre-requisites:

1. User initializes the simulation.
2. E_v and D are simulated and spawned.

Trigger Actions:

1. User starts the simulation.
2. Environment (E_v) and UAV (D) are created.
3. Start main simulation loop

Process Flow:

1. Repeat until STOP condition:
2. Select FM.
3. *if (FM==FM_m)*
4. {
5. *prompt* " user to enter D_n "
6. *goto step 12*
7. }
8. *else(FM==FM_{auto})*
9. {
10. encircle the E_v
11. *goto step 12*
12. }
13. Assign S_{scd}
14. D computes S_{sc} for G_s or C_s or W_s or O_s or S_s
15. $S_{sc} = (SAP_{st} * n_{st}) + (SAP_f * n_f) + (SAP_g * n_g) + (SAP_s * n_s)$

```
Where n ∈ (G_s or O_s or W_s or C_s or S_s)
Compute S_sc
switch (S_sc)
{
   case G_s : if ( S_sc > 0.5 )
               mark D_p1
               break ;
   case O_s : if ( S_sc > 0.5 )
               mark D_p2
               break ;
   case W_s : if ( S_sc > 0.5 )
               mark D_p3
               break ;
   case C_s : if ( S_sc > 0.5 )
               mark D_p4
               break ;
   case S_s : if ( S_sc > 0.5 )
               mark D_p5
               break ;
}
   case A_s : if ( S_sc > 0.5 )
               mark D_p6
               break ;
Assign E_lc
land on {minD_t1, D_t2, D_t3, D_t4, D_t5, D_t6}
```

Post-Process:

1. stores final UAV state.

6.2 Flowchart:

The flowchart basically outlines the entire landing process of a drone. After being launched, the drone switches on the flight mode and prompts an option to either operate autonomous or manual via remote command. In autonomous mode, the drone first confirms if it has been given instructions on a surface scan. As soon as it receives order, it executes a ground scan using its sensors. Otherwise, the drone stays in that mode and flies around the environment until it's instructed to scan. In manual mode, the drone stays on standby waiting for the user to guide it before proceeding. With a manual mode, users control the drone and may also make the surface scan command at will.

Once the drone registers a scan command, the scanning process of the area under the drone begins regardless of the mode it is in. While scanning, the drone collects data and determines a surface score for several spots, marking which ones are safe or the best for landing. Later, it seeks the best place. If a satisfactory landing zone is not found, the drone goes into re-election, scanning

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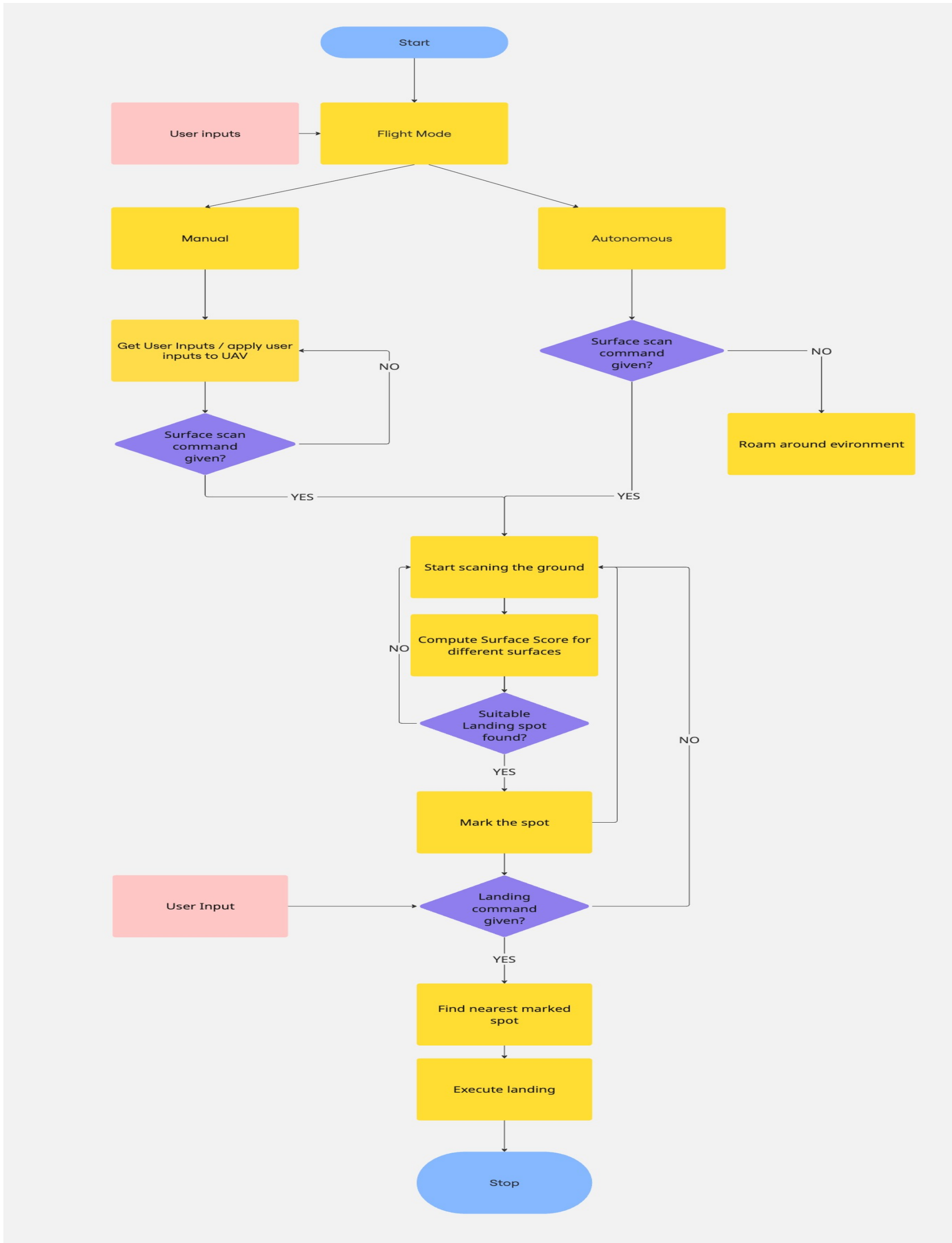

Fig. 2: Flowchart

again and again until it finds a convenient place for a landing. After identifying the best place for landing, the drone digitally locates, flags that area, and waits for instructions from the user before landing. In case, where the user fails to provide the landing instructions, the drone remains active and continues searching for the optimal site. When the UAV is signaled to land, the drone chooses the closest grounded spot and starts sinking down to the ground. When the landing maneuver has been executed, this process ends with all success. As each step is prepared for close examination, the drone ensures safe and intelligent landing by the systematic appraisal of things.

7 Simulation and Results

7.1 Introduction to Simulation:

To visualize our objective we have performed a simulation of a drone in MATLAB version R2024B in an environment containing surfcaes :

1. grassy surface
2. oily surface
3. concrete surface
4. water pond
5. sandy land

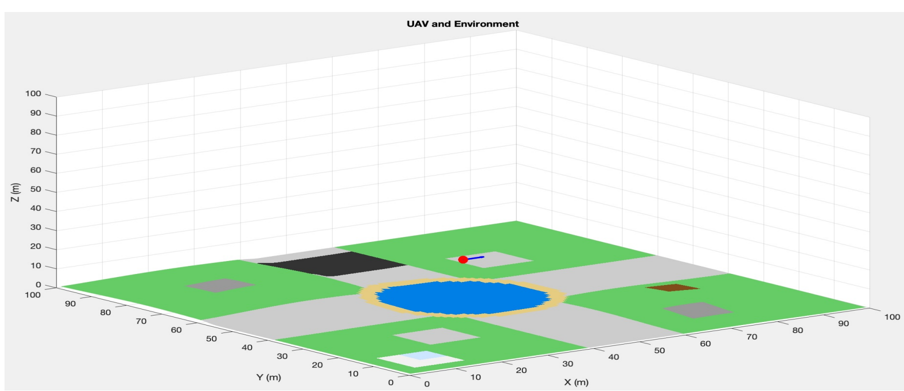

Fig. 3: Simulation Environment

The simulation window shows an area of 100 x 100 m with a UAV and with different surfaces in a dynamic environemt having effect of gravity.

7.2 Snapshot of MATLAB scripts and functions:

In this simulation of MATLAB , we have created different functions of landing , surface evaluation based on different criteria , hovering of UAV , and another important functions necessary for the simulation as shown in the figure 3.

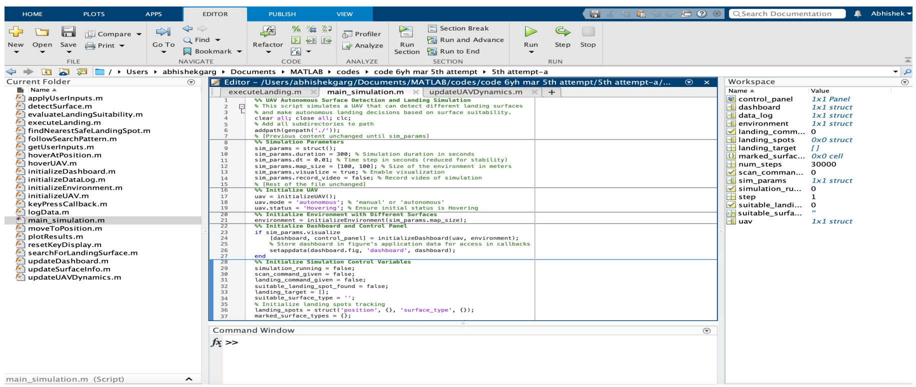

Fig. 4: Snapshot of MATLAB scripts

7.3 Results:

The UAV has successfully landed on the nearest marked safe landing spot with having various environmental factors like wind , gravity with having it's various parameters as results :

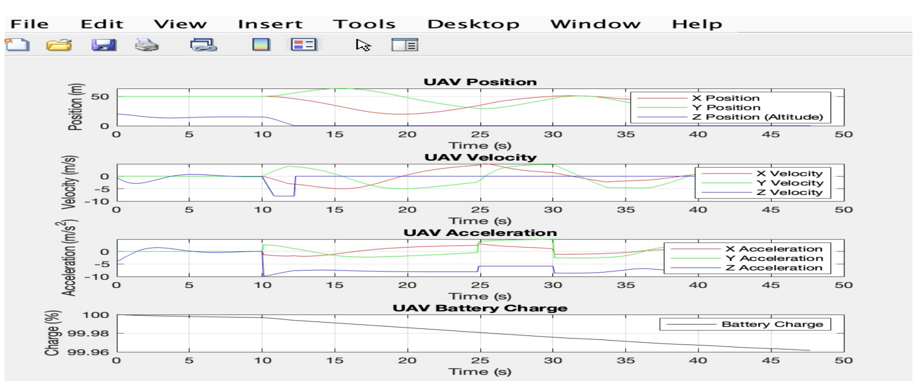

Fig. 5: UAV parameters during time of flight as results

8 Conclusion

Our simulation has successfully detected the safe landing surfaces and landed on the nearest marked safe landing spot autonomously. Drone in the simulation has done:

- **Autonomous Surface detection: -** UAVs had successfully identified, verified the safe landing surface having $S_{sc} < 0.5$ metres.
- **Autonomous landing: -** UAV had landed successfully after reaching at landing spot horizontally first then slowly decends in the z axis.

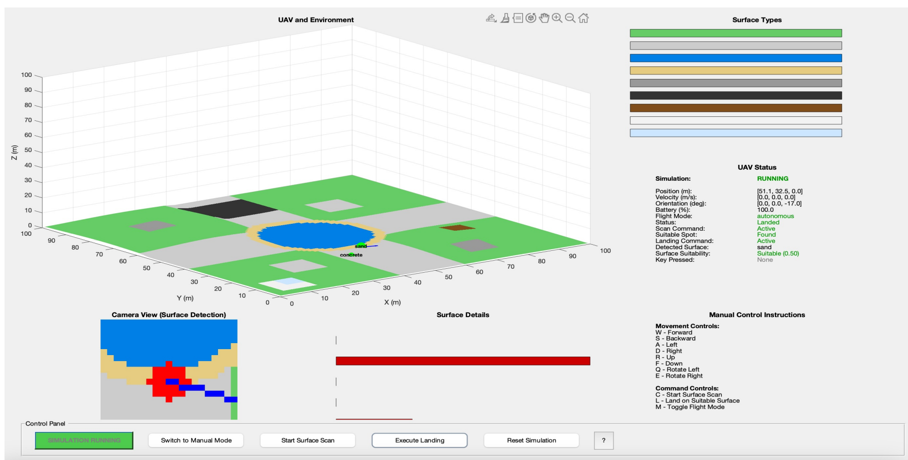

Fig. 6: UAV after landing

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